

PATENT SPECIFICATION



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COMPLETE SPECIFICATION

Improvements in and relating to Methods of and Apparatus for Electro-statically Generating Direct Current Power

We, RESEARCH CORPORATION, a Corporation organised according to the laws of the State of New York, United States of America, of 405 Lexington Avenue, New York City, County and State of New York, United States of America, (Assignees of ROBERT JEMISON VAN DE GRAAFF and JOHN GEORGE TRUMP, both Citizens of the United States of America, of 6 Craigie Circle, Cambridge, Massachusetts, United States of America, and 22 Crescent Road, Belmont, Middlesex, Massachusetts, United States of America, respectively), do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to methods of and apparatus for electrostatically generating direct current power, and especially at high voltages, in usefully large amounts and under conditions assuring practical efficiency and reliability.

It has been recognized that technical and economic problems involved in the transmission of substantial amounts of electric power under high voltages might be lessened by the use of direct current. Certain of these advantages have been pointed out in British Patent No. 407,847. The technical and economic difficulty of producing high voltage direct current power, however, has heretofore prevented any wide use of direct current power for these purposes.

The present invention has for its object, among other things, the efficient electrostatic generation and the transmission to a load circuit of useful amounts of power through methods, which it is believed provide for the first time a practical source of electrostatically generated direct current power.

Another object of the invention is to avail of the advantages of superior insulating media, such as carbon tetrachloride in gaseous state, or other compounds of like insulating properties, or gases at high pressure, or on the other hand highly rarefied media such as a high

vacuum characterized by a pressure, for example, of the order of 10^{-5} millimeters of mercury, and to produce a novel type of electrostatic generator so constructed as to best avail of these high voltage vacuum insulating media and possessing the qualifications of efficiency and reliability as well as high power capacity per unit size or weight for use under practical conditions in the generation and transmission of high voltage direct current power. In the present application the electrostatic generator, for illustrative purposes, is shown as arranged for operation in a high vacuum.

The method of electrostatically generating direct current power and applying the same to a load circuit according to the invention consists in varying between maximum and minimum the capacitance of two bodies comprising charge-inducing and charge-receiving members, causing a charge to pass from the lower potential side of the load circuit to the charge-receiving member during periods of increasing capacitance and from the charge-receiving member to the higher potential side of the load circuit during periods of lessening capacitance, the passage of the charges taking place unidirectionally under the influences of potential differences slight with relation to the load circuit voltage and involving an energy loss small as compared with the energy usefully transferred to the load circuit.

The objects of the invention referred to above and other objects will be best understood by reference to the following description, when taken in connection with the accompanying illustration of one specific embodiment thereof, while its scope will be more particularly pointed out in the appended claims.

In the drawings:—

Fig. 1 is an elevation in partial cross-section of one form of apparatus adapted electrostatically to generate high voltage power and deliver it in the form of unidirectional current to a line;

Fig. 2 is a transverse, sectional plan on the line 2—2 of Fig. 1;

Fig. 3 is a view showing diagrammatic-

[Price 4/6]

ally the apparatus of Fig. 1 and its electrical connections and illustrative of its mode of operation;

Fig. 4 is a view illustrating diagrammatically the sectionalized arrangement of the generator for producing a substantially steady flow of unidirectional current;

Figs. 5 and 6 are fragmentary views illustrating in section and elevation, respectively, the relative arrangement of the stator and rotor parts in the case of the illustrative sectionalized arrangement; and

Fig. 7 is a view more or less diagrammatic showing the generator and load insulated in the same insulating medium.

Referring to the drawings and to the embodiment of the invention there shown for illustrative purposes, the generating, and preferably the devices for transferring charges to the line, are mounted inside a container 11, providing a hermetically sealed chamber, evacuated and maintained evacuated to a degree where the insulation of extremely high voltages with short electrode separations is possible. High vacuum may be maintained within the chamber by means of an efficient, high speed, high vacuum pump indicated diagrammatically at 13. The walls of the container, for practical reasons, are preferably metallic, and are grounded to avoid hazard.

The means for electrostatically inducing the required charges comprise relatively rotatable charge inducing and charge receiving elements contained within the evacuated chamber. Either the charge inducing or charge receiving element might be rotatable and the other stationary, or both might be rotated, but herein, to avoid mechanical stresses, secure a simplified and efficient mechanical arrangement and to eliminate some electrical problems in maintaining electrical contact between relatively movable parts, the charge receiving element is in the form of a stator 15, while the charge inducing element is in the form of a rotor 17.

Referring to the rotor, the latter comprises one or more (herein ten) multipolar members consisting each of sector shaped poles or plates 19 of conductive metal, each member comprising a number (herein sixteen) of poles lying in the same plane in equally spaced radial relation and having a common (and herein vertical) axis of rotation. The poles of each member are mounted on and in conductive relation to, or (as indicated in the drawings) may be formed integrally with, a common metallic rotatable hub member 21, which in turn is connected to be driven by a driv-

ing shaft 23 from any suitable source of external power, such as a turbine motor (not shown). In the construction shown in Figs. 1 and 2, poles of adjoining members are angularly aligned with each other lengthwise the axis of the rotor.

The driving shaft 23 drives the hub 21 through an insulating member 25 within the chamber, such member being rigidly connected to both the shaft and the hub. The shaft, mounted in a ball thrust bearing in the bottom walls of the chamber protrudes through and beyond the wall thereof.

A vacuum seal indicated at 27, and which may be of the nature described in Patent No. 407,847, is employed for sealing the joint between the protruding end of the shaft and the walls of the container against impairment of the high vacuum maintained within the chamber. The opposite end of the hub is mounted in ball bearings carried by an insulating member 29 supported on the stator shell, herein-after referred to. The rotor, accordingly, comprises a unitary multi-polar structure entirely of conductive metal insulated from its surroundings, and each pole of the several members constitutes a charge inducing element.

In the operation of the machine, the rotor is permanently and continuously connected to an independent source of high potential of constant polarity, preferably but not necessarily outside the chamber, for the purpose of inducing charges on the stator. This independent source of high potential serves merely the function of inducing electric charges on the stator, and only a small amount of electric energy required to maintain this potential is needed for this function. Such potential source (indicated diagrammatically at 31) preferably comprises electromagnetic means and may, for example, consist of a transformer connected to a source of alternating current and having one terminal on its high potential winding connected through a rectifier to the rotor and the other terminal to ground. The source of inducing potential should preferably have a high electrical capacitance relative to the rotor-stator capacitance in order to minimise current fluctuations. The potential source 31 has connection to the rotor through a conductor 33 passing through an insulating bushing 35 supported on the walls of the container into the chamber and having at its end a brush 37, or other suitable contact device, for making continuous contact with the exposed end of the rotary hub 21.

Referring to the stator 15, the latter comprises a stationary cylindrical metallic

shell 39 surrounding but spaced from the periphery of the rotor and having longitudinally spaced members (herein eleven in number) of metallic sector shaped poles 41 projecting inwardly from the shell in very closely spaced and interleaving relation to and on opposite sides of the rotor poles 19. The poles of the stator members conform substantially to the spacing, area and shape, of the rotor poles and terminate short of the periphery of the hub 21.

The stator structure, the poles and shell of which also comprise a unitary multipolar structure of conductive metal, is insulated from the walls of the chamber of the container, being supported by the bottom wall thereof through a suitable number of insulators, one of which is shown at 42 in the section in Fig. 1. These and other insulators employed within the evacuated chamber preferably embody the principles of the insulators for the support of high voltage electrodes in vacuum set forth in patent No. 407,847.

It will be seen that the stationary members and the closely adjacent but spaced members of the rotor constitute multipolar means for varying the capacitance of the rotor-stator structure from a maximum capacitance, when rotation has brought the rotor poles into a position where they align with the stator poles, to a minimum capacitance, when rotation has brought the rotor poles into a position where they align with the spaces between adjoining stator poles. The potential of constant polarity continuously applied to the unitary multipolar structure of the rotor results in the induction of electrical charges on the stator.

Means are herein provided for causing the charge thus induced to be transferred to a load circuit in the form of a unidirectional current under the influence of low potential differences. While this might be accomplished by other means, such as commutating devices, herein, to avoid difficulties of synchronizing such devices and their adjustment to meet changing load conditions, and further to avoid mechanical difficulties, there are employed electronic rectifiers or valves 43 and 45. To simplify the construction of such rectifiers and avoid the necessity of individual evacuated glass or other envelopes, these rectifiers are also contained within the evacuated chamber itself. With insulating media other than vacuum, these electronic devices would obviously retain their evacuated envelopes.

In the form of the invention shown in Fig. 1, the rectifier 43 comprises a metallic cup 47 in permanent electrical connection to, and herein supported on, the shell 39

of the stator. Within but spaced from the surrounding walls of the cup is a filament 49, the terminals of which pass through the insulating bushing 51 to the exterior of the chamber. They are there included in a circuit 53 having any suitable source of filament excitation, which, for illustration, is indicated as a battery 55, the circuit having a ground connection 57 which may be regarded as the low potential side of the load circuit. Although here shown outside of the chamber 11, the circuit 53 and source of filament power might be positioned within the chamber.

The second rectifier 45 comprises a filament 59 contained within and spaced from the walls of a metallic cup 61. The filament 59 is included in a circuit 63, also containing a source of excitation. The latter might be a generator driven through an insulating link by the rotor, but herein is also diagrammatically indicated as a battery or dry cell 65. The circuit 63 is electrically connected to the stator shell at 67 so that its potential rises and falls with that of the stator. The cup 61 is supported by a conductor 69 which passes through insulating bushing 71 on the walls of the container, passing through the bushing to the exterior of the evacuated chamber, where it has connection to a load circuit indicated at 73.

The action of the apparatus will best be understood from the diagrammatic representation in Fig. 3, in which the stator is represented by the charge receiving member 15 and the rotor by the charge inducing member 17, the latter continuously maintained at a substantially high potential V which is positive to ground and is supplied from the potential source 31 of constant polarity outside of the casing 11 of the evacuated chamber, the walls of which are indicated in dotted lines. The rotor is represented as movable with relation to the stator about the axis 21, in the path represented by dotted lines in the direction of the arrow, moving from a position A, corresponding to maximum rotor-stator capacitance, to a position B, corresponding to minimum rotor-stator capacitance. The power output of the generator is assumed to be applied at an essentially constant load voltage E to an output circuit 73 having a resistance load R_L and a capacitance load C_L in parallel, the low potential side of the load being grounded at G.

At the beginning of the cycle, when the rotor and stator are in position A, corresponding to maximum rotor-stator capacitance, this capacitance is charged to the full value of the inducing potential V . At this point in the cycle, the stator, because of the immediately preceding

cycle, as will hereafter appear, is substantially at ground potential. The valve 45 is withstanding the load voltage E which is negative to ground and the valve 43 has just ceased conducting. Succeeding movement of the rotor causes the rotor-stator capacitance to diminish, and hence an increase of the stator potential with relation to ground. The potential across the valve 45 is diminished by the amount of this increase, while the potential across the valve 43 is increased by this amount. This continues until a point is reached where the stator has acquired the potential E of the output circuit. Further movement of the rotor toward the position of minimum capacitance then causes a charge to flow through the valve 45 into the output circuit, a process which continues until position B, corresponding to minimum rotor-stator capacitance, is reached. During this interval from position A to position B the source of mechanical power, acting through the driving shaft 23 and causing the rotor to turn, is the agency which results in raising the stator potential with relation to the line potential and in the flow of stator charge out to the line. The movement of the rotor beyond position B now results in an increase of rotor-stator capacitance, causing the potential of the stator to fall rapidly back to ground potential. Further movement of the rotor from the point at which the stator reaches ground potential makes the stator positive relative to ground and causes the valve 43 to conduct. The consequent flow of electrons to the stator persists until the position of maximum rotor-stator capacitance is reached. The flow of electrons to the stator eventually brings the stator to ground potential. This corresponds to the starting point of the cycle and the process is repeated.

In this explanation it is assumed that the voltage drops across the valves during conduction intervals are negligible in comparison with inducing voltage V.

It is evident that the output current supplied by the machine as described, though unidirectional, tends to flow in pulses which depend on the variations in the rotor-stator capacitance and on the output and inducing potential. The use of a load capacitance large in comparison to the rotor-stator capacitance would be effective in smoothing out the voltage pulsations resulting from this discontinuous current flow.

A substantially steady flow of current, however, may be produced by providing separate units having each its own rectifying system, the action of such units being in staggered or overlapping time

relation so that the current impulses of the several units succeed each other to give the effect on the output circuit of a substantially continuous current flow. In a generator of the type shown in Figs. 1 and 2, this result may be secured by a slight modification in the construction of the rotor and stator. Such a construction is indicated in Figs. 5 and 6, where the generator is separated into four units or sections.

In this form of apparatus, the stator (Fig. 5), instead of having a common metallic shell, is separated into four sections consisting each of an annular ring 75 with inwardly extending sector shaped poles 77, the rings of the several sections, however, being insulated from each other by the insulators 79. In an axial direction, the poles 77 of the successive sections are aligned with each other.

The rotor comprises a single unitary conductive structure mounted on the same rotary hub with the poles 81 of the several sections maintained at a continuously high potential from the same potential source. It is of a construction similar to that illustrated in connection with Figs. 1 and 2, save for the fact that the sector shaped poles of each one of the four sections are offset angularly about the axis of rotation from the poles of the next adjoining section, so that the poles of successive sections reach and recede from their positions of maximum rotor-stator capacitance in succession and in equally spaced timed relation. The same result may be accomplished by angularly offsetting the poles of the several stator sections instead of the poles of the rotor sections. If, for example, each rotor and stator member comprises sixteen poles, as in the construction of Fig. 2, where the sector shaped poles are positioned about the axis of rotation at intervals of $22\frac{1}{2}^\circ$ (representing one cycle of generator operation), the rotor sections are spaced around the hub so that the poles of one section are $5\frac{5}{8}^\circ$ in advance of the poles of the next succeeding section. Such relationship is indicated in Fig. 6, where the position of two adjoining stator poles 77 is shown in dotted lines and the positions of the poles of the four different rotor sections are indicated at one particular stage of rotation. It will be observed that when the rotor pole 81^a of one section reaches its position of maximum capacitance, the pole 81^b of the next section is half way from that position and approaching the position of minimum capacitance, the pole 81^c of the next section at the position of minimum capacitance, and the pole 81^d of the fourth

section half way from the latter position and approaching that of maximum capacitance.

For simplification, Fig. 5 illustrates each section as consisting of a single rotor member in interleaving relation between two stator members, but each section may comprise as many rotor and stator members as desired.

The rectifying system, in case of the illustrative sectionalized arrangement of the generator, is indicated in Fig. 4, where the four separate insulated stator sections 15^a, 15^b, 15^c and 15^d are in interleaved relation, respectively, to the rotors 17^a, 17^b, 17^c and 17^d, the latter, however, being each electrically connected to the same source of inducing potential 31. Each stator, however, is provided with its own two rectifying valves, the stator 15^a being connected to the valves 43^a and 45^a, the stator 15^b to the valves 43^b and 45^b, and so on, each of the valves 43 being connected to the ground and each of the valves 45 being connected to the load or output circuit 73.

The power which can be delivered by an electrostatic generating apparatus of the type described may be illustrated by the following example.

If it is assumed that the rotor (as in Figs. 1 and 2) has ten members of sixteen poles each with an external rotor diameter of 24 inches and a hub diameter of 6 inches and the separation between the adjoining rotor and stator poles is 6 millimeters, and it is further assumed that the rotor is rotated at a speed of 3600 revolutions per minute, with a substantially constant output voltage E at 100,000 volts and a constant inducing potential V at 100,000 volts impressed on the rotor, then the electrical power output of such a machine would be about 20 kilowatts. It will be seen that, under these assumptions, a machine of these physical characteristics possesses a power compactness comparable with present electro-magnetic machines and makes available in a single unit electrostatically generated direct current power of very high voltage.

To provide for proper surface conditions of the electrodes and insulators and adequate vacuum insulation, the vacuum maintained in the chamber enclosing such an illustrative machine should preferably be of the order of 10^{-5} millimeters of mercury or better.

Applicants' investigations on the insulating properties of vacuum and material insulation show that between suitable metallic electrodes held apart in vacuum voltages as high as 10000 can be insulated with gradients of about

5,000,000 volts per centimeter. When the potential difference is 100,000 volts, gradients somewhat greater than 1,000,000 per centimeter can be insulated.

With voltages of the order of 500,000 volts, a gradient which can be insulated is about 100,000 per centimeter. These voltages and gradients which can be insulated are of the same order of magnitude as those utilized in the above illustrative machine, and the application of these principles to the electrostatic generator permits the attainment of high voltage and substantial power with compact insulation.

It may be observed that generators, typified by the illustrative example, not only provide for the practical attainment of high voltage output but are inherently capable of extremely high efficiency. Electrostatic machines of the type herein described have shown an electrical efficiency of about 99% under actual working conditions. Such high efficiency is due not only to the absence of magnetic losses and to the extremely small dielectric and resistance losses which characterize the operation of electrostatic machinery adequately insulated in vacuum or high insulating gaseous media, but is due also to the efficiency of the charge transferring process employed. For example, if a charged condenser be connected across a second and uncharged condenser of equal capacitance, then, regardless of the resistance of the circuit, an amount of energy equal to twice the energy transferred is lost as heat. In a machine of the type herein described, due to the method and means for effecting such transfer, the transfer of charges between the charge receiving element and the terminals of the load circuit are effected at points in the cycle of operation of the machine when the potential differences between such charge receiving element and such terminals are but slightly different and substantially the same, so that the efficiency of the charge transferring process is extremely high. Such high inherent efficiency is absent in various forms of electrostatic machines of the conventional type of the prior art.

The necessary commutation is herein performed electronically and, when vacuum insulation is employed, preferably with the filament and plate housed in the same vacuum as the machine itself. This eliminates the necessity of glass or other envelopes and avoids flashing over and other voltage limitations where such enveloped valves are employed in the atmosphere. It further avoids the necessity of bringing out the high voltage connections through bushings into the atmosphere, and further simplifies the construction in that it very materially

reduces the space occupied by such valves when placed in vacuum without the usual insulating envelopes.

Whether used in vacuum or with other insulating media, the electronic commutation automatically adjusts itself to any load condition, the electronic valves becoming conducting or insulating at precisely the desired point in the cycle of operation and in a manner which cannot be obtained readily by mechanical commutating devices. Mechanical commutation alone, however, may be employed or may be employed in conjunction with electronic valves to relieve the valves of the necessity of withstanding all the voltage difference between the line terminals and the stator.

It will be further observed that the method of charge induction and charge transfer here utilized permits the effective use of the charge receiving element in the form of a single unitary multipolar structure of conductive metal throughout, insulated from the walls of the chamber by simple compact stationary insulators. It further permits the use of a rotor, also in the form of a single unitary multipolar structure of conductive metal throughout, insuring the necessary ruggedness for high speed rotation and the required reliability for practical, high voltage, load requirements. The demonstrated advantages of vacuum insulation and the properties of material insulation for the electrodes in vacuum can thus be most effectively applied to the insulation of the relatively movable interleaving electrodes as can the superior qualities of the other insulating media referred to.

The interleaving type of construction is of a form which permits a maximum capacitance variation per unit size machine, and is capable of high speed rotation. It is particularly adapted to the multipolar construction, which is important since, under certain practical conditions of operation and for a given speed of rotation, the power produced by the generator is approximately proportional to the number of poles.

For certain useful purposes, such, for example as the production of high voltage X-rays or other high energy radiations, in which the source of radiation constitutes the load on the generator, the entire load circuit, with the energy translating elements constituting the load, may be contained within the same evacuated chamber as encloses the generator itself.

Such an arrangement is indicated in partially diagrammatic form in Fig. 7, where the generator within the casing 11 and its electrical connections are substantially as shown in Fig. 1. The load,

however, is provided by the flow of electrons from a filament heating circuit 85, also surrounded by the insulating medium, and positioned within the metallic cup 87. In line with and opposed to the filament and the radiations therefrom there is positioned at the end of the tubular extension 89 of the casing 11 an X-ray target 91 which may be air or water cooled. The tubular extension is enclosed by a lead sheathing 93 presenting in front of the target a portal 95 to provide for the emission of the high voltage X-rays.

To provide the desired capacitance for the load circuit, there is provided the condenser 97 having one side grounded to the container casing and the other side connected to the cup 61 of the valve 45 and also to the cup 87 of the filament. The filament heating circuit may be arranged for external control, as by a rheostat (not shown) operated through an insulating link.

While the continuously applied inducing voltage V may be supplied by a battery system, electrostatic devices or other means, it is preferably supplied by an electro-magnetic device, such as the transformer rectifier instanced, equipped with means for controlling the potential applied to the rotor. Since the ratio of the maximum to the minimum rotor-stator capacitance is fixed by the design of the machine, variation in the potential applied to the rotor provides means for definitely controlling both the potential and power output of the generator.

Having now particularly described and ascertained the nature of our said invention, and in what manner the same is to be performed, we declare that what we claim is:—

1. The method of electrostatically generating direct current power and applying the same to a load circuit, which consists in varying between maximum and minimum the capacitance of two bodies comprising charge-inducing and charge-receiving members, causing a charge to pass from the lower potential side of the load circuit to the charge-receiving member during periods of increasing capacitance and from the charge-receiving member to the higher potential side of the load circuit during periods of lessening capacitance, the passage of the charges taking place unidirectionally under the influences of potential differences slight with relation to the load circuit voltage and involving an energy loss small as compared with the energy usefully transferred to the load circuit.

2. The method as claimed in Claim 1, in which there is continuously impressed on

the charge-inducing member a high potential of constant polarity.

3. The method as claimed in either Claim 1 or 2, in which the charge-inducing and charge-receiving members are within a closed container and surrounded by a highly insulating medium.

4. The method as claimed in any of Claims 1, 2 or 3, in which charges are induced in staggered time relation and separately transferred to the load circuit, also in staggered time relation, to smooth out pulsations resulting from discontinuous current flow.

5. An electrostatic generating apparatus for use in the method of any of Claims 1 to 4 inclusive, characterized by relatively movable charge-inducing and charge-receiving members adapted alternately to assume positions of maximum and minimum capacitance, and by means to cause a charge to pass unidirectionally from the lower potential side of the load circuit to the charge-receiving member during periods of increasing capacitance and from the charge-receiving member to the higher potential side of the load circuit during periods of lessening capacitance and under the influence of potential differences slight with relation to the load circuit voltage.

6. An electrostatic generating apparatus according to Claim 5, in which means for causing the passage of the charges between the charge-receiving member and the lower and higher potential sides of the load circuit comprise an ionic rectifier between one side of the load circuit and the charge-receiving member and an ionic rectifier between the charge-receiving member and the other side of the load circuit.

7. An electrostatic generating apparatus according to either Claim 5 or 6, in which there is continuously impressed on the charge-inducing member a high potential of constant polarity.

8. An electrostatic generating apparatus according to Claim 7, in which the high potential impressed on the charge-inducing member is derived from a separate source.

9. An electrostatic generating apparatus according to any of Claims 5 to 8 inclusive, in which the charge-inducing and charge-receiving members are within a closed container and surrounded by a highly insulating medium.

10. An electrostatic generating apparatus according to Claims 6 and 9, in which the ionic rectifiers are also within a closed container and surrounded by a highly insulating medium.

11. An electrostatic generating apparatus according to any of Claims 5 to 10 inclusive, in which the apparatus comprises a plurality of units each with charge-inducing and charge-receiving members, the units being related to reach a position of maximum capacitance at successive intervals, and in which the charges are transferred from the several units to the load circuit in succession or staggered time relation, thereby to smooth out pulsations resulting from discontinuous current flow.

12. An electrostatic generating apparatus according to Claim 11, in which the charge-receiving members are comprised in a single structure, with members of one unit insulated from those of another unit but related to each other to reach a position of maximum capacitance at successive intervals.

13. The invention according to either Claim 9 or 10, in which the load circuit with its load is also contained within a container and surrounded by a highly insulating medium.

14. An electrostatic generating apparatus according to Claim 13, in which the load comprises means energized by the generated power for the acceleration of charged particles.

15. An electrostatic generating apparatus according to any of Claims 5 to 14 inclusive, in which both the charge-inducing member and the charge-receiving member comprise a plurality of metallic segmented disks, those of the charge-inducing member being closely spaced and in interleaving relation to those of the charge-receiving member.

16. An electrostatic generating apparatus according to any of Claims 5 to 15 inclusive, in which the charge-receiving member is in the form of a stator and the charge-inducing member is in the form of a rotor.

17. The improved method of electrostatically generating direct current power and applying the same to a load circuit, substantially as herein described and for the purposes specified.

18. An electrostatic generating apparatus for use in the method set forth in any of Claims 1 to 4 inclusive, substantially as herein described and for the purposes specified.

Dated this 17th day of May, 1938.

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London, W.C.2.

[This Drawing is a reproduction of the Original on a reduced scale.]

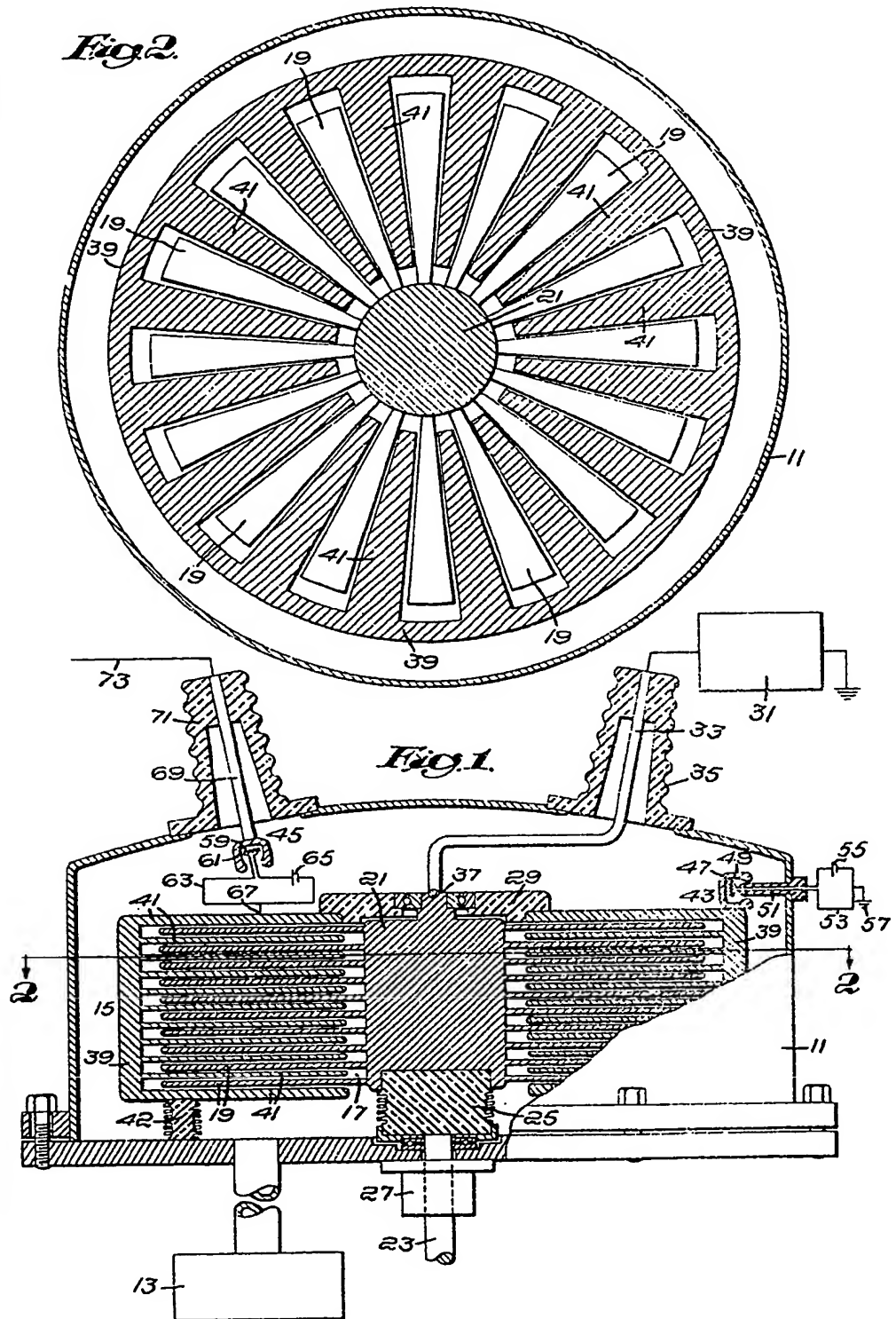


Fig. 3.

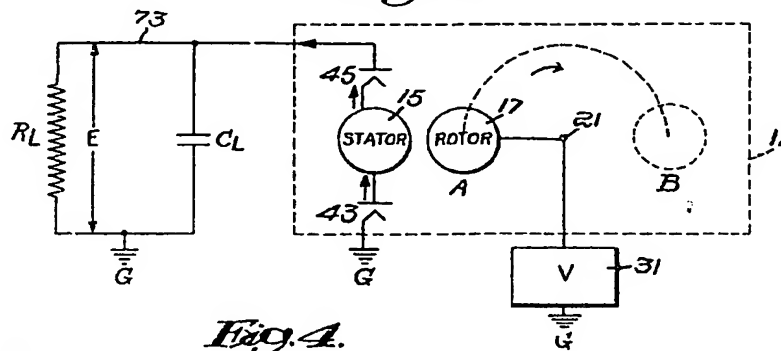


Fig. 4.

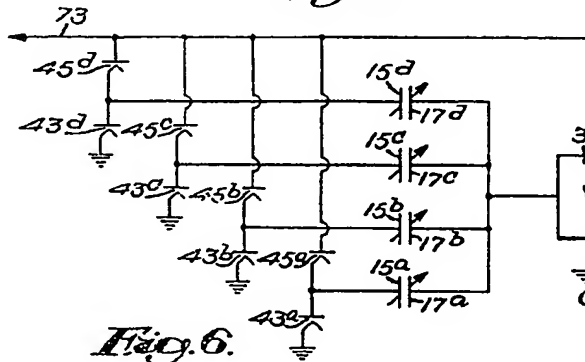


Fig. 6.

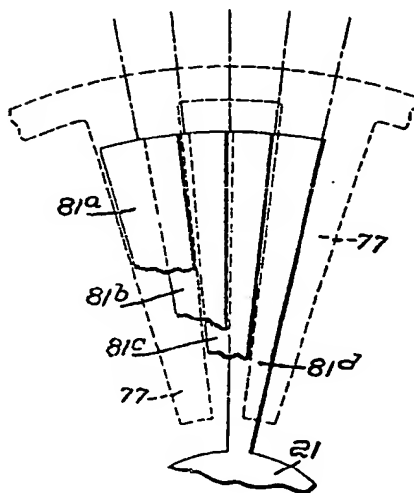


Fig. 5.

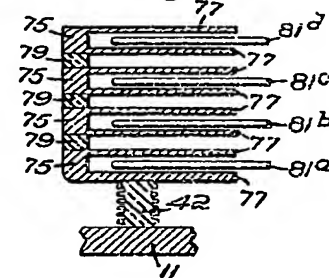
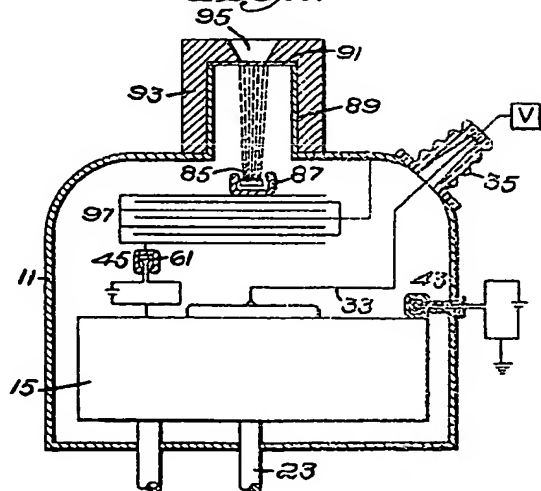


Fig. 7.



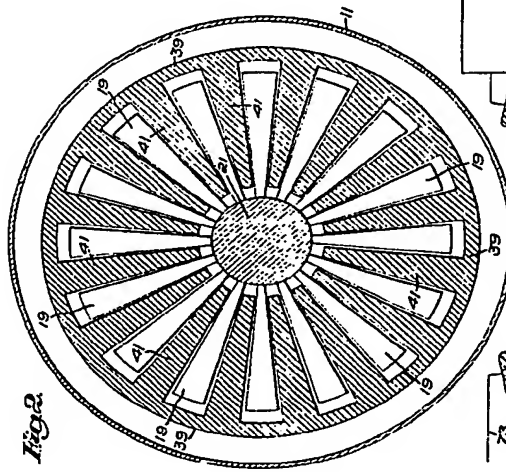


Fig. 2.

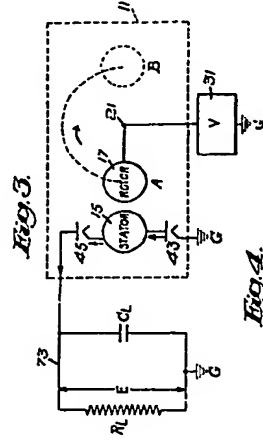


Fig. 3.

Fig. 4.

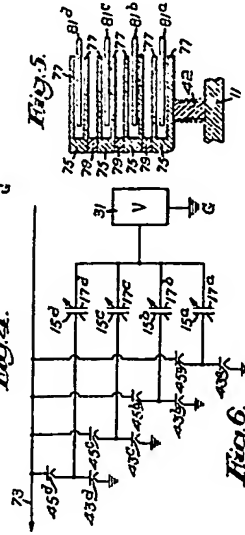


Fig. 5.

Fig. 6.

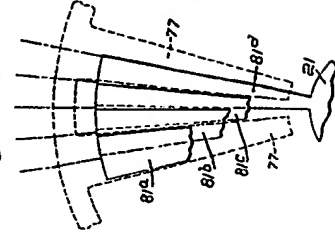


Fig. 7.

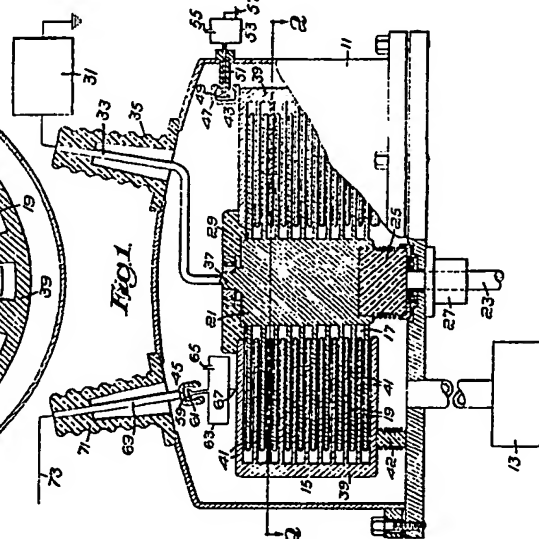
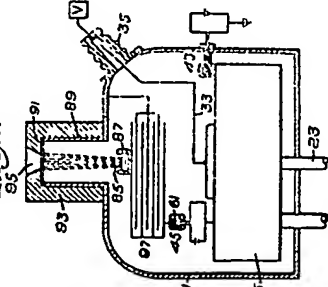


Fig. 1.

[This Drawing is a reproduction of the Original on a reduced scale.]

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